CLAIMS

What is claimed is:

1.   A method for color matching a first image and a second image, wherein a first region of the first image and a second region of the second image overlap, the method comprising:

generating a first histogram of the first region;

generating a second histogram of the second region;

determining corresponding pixel values from the first and the second histograms;

determining at least one parameter of an optoelectronic conversion function (OECF) that best matches the corresponding pixel values; and

color matching the second image to the first image by applying the OECF with the at least one parameter to the second image.

2.   The method of claim 1, further comprising, prior to said generating a first histogram and generating a second histogram:

removing a percentage of the overlapping pixels with the greatest difference in brightness.

3.   The method of claim 1, wherein:

said generating a first histogram comprises recording in a first plurality of pixel value bins a first plurality of numbers of pixels that have respective pixel values in the first region; and

said generating a second histogram comprises recording in a second plurality of pixel value bins a second plurality of numbers of pixels that have the respective pixel values in the second region.

4. The method of claim 3, wherein said determining corresponding pixel values in the first and the second histograms comprises generating a lookup table (LUT) storing a third plurality of numbers of pixels and their corresponding pixel values.

5. The method of claim 4, wherein said generating a lookup table comprises:

(1) initializing all entries in the LUT to 0;

(2) initializing a first loop by setting $i = 0$; $j = 0$; $rem1$ = h1[0]; and $rem2$ = h2[0];

(3) updating the LUT by setting min_rem = $min(rem1, rem2)$; $rem1 = rem1 - min\_rem$; and $rem2 = rem2 - min\_rem$; and incrementing LUT[i][j] by min_rem;

(4) if $rem1 = 0$, then incrementing i and setting $rem1$ = h1[i];

(5) if $rem2 = 0$, then incrementing j and setting $rem2$ = h2[j];

(6) if $i < 256$ and $j < 256$, then repeating steps (3) to (5);

wherein h1[] is the number of pixels having a certain pixel value in the first histogram, h2[] is the number of pixels having a certain pixel value in the second histogram, and LUT[][] is the number of pairs of corresponding pixel values having a certain pixel value in the first histogram and a certain pixel value in the second histogram.

6. The method of claim 5, wherein said determining at least one parameter of an OECF comprises minimizing a color matching error, the color matching error being defined as:

$$e = \sum_{i=0}^{255} \sum_{j=0}^{255} LUT[i][j]((i+1)/256.0 - S^{-1}(\tau S((j+1)/256.0))),$$

wherein e is the color matching error, τ is a color matching parameter, and $S()$ is the OECF.

7. The method of claim 6, wherein the OECF is defined as:

$$S(x) = x + \frac{2}{\pi} arctan\left(\frac{a\,sin(\pi x)}{1 - a\,cos(\pi x)}\right),$$

wherein x is a pixel value normalized to $(0,1)$, and $a \in (-1,1)$ is another color matching parameter.

8.   The method of claim 7, wherein said minimizing a color matching error comprises performing a golden section search of the color matching error.

9.   The method of claim 8, wherein said performing a golden section search comprises:

(1) initializing the another color matching parameter and a minimum color matching error;

(2) performing the golden section search with the another color matching parameter being fixed and the color matching parameter being varied to determine a smallest color matching error achieved;

(3) recording values of the color matching parameter and the another color matching parameter that achieve the smallest color matching error if it is less than the minimum color matching error;

(4) setting the minimum color matching error equal to the smallest color matching error; and

(4) repeating steps (2) to (4) for a range of values of the another color matching parameter.

10.   The method of claim 6, wherein said applying the optoelectronic conversion function comprises:

$$x_c = S^{-1}(W(\tau,x_o)S(x_o)),$$

wherein x_o is an original pixel value in the second image, x_c is a corrected pixel value in the second image, $S^{-1}()$ is the inverse of the OECF, and W is a weight funciton defined as:

$$W(\tau,x_1) = \tau + (1-\tau)x_1.$$

11.   The method of claim 1, wherein the OECF is defined as:

$$S(x) = x + \frac{2}{\pi} arctan\left(\frac{a\,sin(\pi x)}{1 - a\,cos(\pi x)}\right),$$

wherein $S()$ is the OECF, x is a pixel value normalized to $(0,1)$, and $a \in (-1,1)$ is a first color matching parameter.

12. The method of claim 11, wherein said determining at least one parameter of an OECF comprises minimizing a color matching error defined as:

$$e = \sum_{x_1 \in \Re_1, x_2 \in \Re_2} \left\| x_1 - S^{-1}(\tau S(x_2)) \right\|^2,$$

wherein e is the color matching error, x_1 and x_2 are corresponding pixel values in the first and the second regions, R_1 and R_2 are the first and the second regions, $S()$ is the OECF, $S()^{-1}$ is the inverse OECF, and τ is a second color matching parameter.

13. The method of claim 12, wherein said minimizing a color matching error comprises performing a golden section search of the color matching error.

14. The method of claim 13, wherein said performing a golden section search comprises:

(1) initializing the first color matching parameter and a minimum color matching error;

(2) performing the golden section search with the first color matching parameter being fixed and the second color matching parameter being varied to determine a smallest color matching error achieved;

(3) recording values of the first and the second color matching parameters that achieve the smallest color matching error if it is less than the minimum color matching error;

(4) setting the minimum color matching error equal to the smallest color matching error; and

(4) repeating steps (2) to (4) for a range of values of the first color matching parameter.

15. The method of claim 12, wherein said applying the OECF comprises:

$$x_c = S^{-1}(W(\tau, x_o)S(x_o)),$$

wherein x_o is an original pixel value in the second image, x_c is a corrected pixel value in the second image, and W is a weight function defined as:

$$W(\tau, x_1) = \tau + (1-\tau)x_1.$$

16. A method for color matching a first image and a second image, wherein a first region of the first image and a second region of the second image overlap, the method comprising:

removing a percentage of overlapping pixels with the greatest difference in brightness;

generating a first histogram of the first region and a second histogram of the second region after said removing;

histogram matching the first and the second histogram to determine corresponding pixel values from the first and the second histograms;

minimizing a color matching error between the corresponding pixel values, wherein the color matching error is generated from an optoelectronic conversion function (OECF); and

color matching the second image to the first image by applying the OECF to the second image.

17. The method of claim 16, wherein said histogram matching the first and the second histograms comprises generating a lookup table (LUT) as follows:

(1) initializing all entries in the LUT to 0;

(2) initializing a first loop by setting $i = 0$; $j = 0$; *rem1* = h1[0]; and *rem2* = h2[0];

(3) updating the LUT by setting *min_rem* = min(*rem1*, *rem2*); *rem1* = *rem1* − *min_rem*; and *rem2* = *rem2* − *min_rem*; and incrementing LUT[i][j] by *min_rem*;

(4) if *rem1* = 0, then incrementing i and setting *rem1* = h1[i];

(5) if *rem2* = 0, then incrementing j and setting *rem2* = h2[j];

(6) if $i < 256$ and $j < 256$, then repeating steps (3) to (5);

wherein h1[] is the number of pixels having a certain pixel value in the first histogram, h2[] is the number of pixels having a certain pixel value in the second histogram, and LUT[][] is the number of pairs of corresponding pixel values having a certain pixel value in the first histogram and a certain pixel value in the second histogram.

18.   The method of claim 17, wherein said determining parameters of the OECF comprises minimizing a color matching error, the color matching error being defined as:

$$e = \sum_{i=0}^{255} \sum_{j=0}^{255} LUT[i][j]((i+1)/256.0 - S^{-1}(\tau S((j+1)/256.0))),$$

wherein e is the color matching error, τ is a color matching parameter and $S()$ is the OECF defined as:

$$S(x) = x + \frac{2}{\pi} arctan\left(\frac{a\,sin(\pi x)}{1 - a\,cos(\pi x)}\right),$$

wherein $S()$ is the OECF, x is a pixel value normalized to (0,1), and $a \in (-1,1)$ is another color matching parameter.

19.   The method of claim 18, wherein said minimizing a color matching error comprises performing a golden section search of the color matching error comprising:

(1) initializing the another color matching parameter and a minimum color matching error;

(2) performing the golden section search with the another color matching parameter being fixed and the color matching parameter being varied to determine a smallest color matching error achieved;

(3) recording values of the color matching parameter and the another color matching parameter that achieve the smallest color matching error if it is less than the minimum color matching error;

(4) setting the minimum color matching error equal to the smallest color matching error; and

(5) repeating steps (2) to (4) for a range of values of the another color matching parameter.

20.   The method of claim 19, wherein said applying the optoelectronic conversion function comprises:

$$x_c = S^{-1}(W(\tau,x_o)S(x_o)),$$

wherein x_o is an original pixel value in the second image, x_c is a corrected pixel value of the second image, and W is a weight function defined as:

$$W(\tau,x_1) = \tau + (1-\tau)x_1.$$